

## **Report for 2003IN110B: Minimizing Runoff and Nonpoint Source Pollution Due to Urbanization**

There are no reported publications resulting from this project.

Report Follows

## Minimizing Runoff and Nonpoint Source Pollution Due to Urbanization

### **Problem:**

Urban expansion requires the careful selection of areas for development or urbanization to ensure sustainable environmental development. One of the major direct environmental impacts caused by the conversion of open spaces to impervious urban and suburban areas is the degradation of water resources and water quality (EPA, 2001). The impact of urbanization on water resources is typically reflected in the alteration of the natural hydrological systems in terms of increasing the runoff rate and volume and decreasing infiltration, ground water recharge, and base flow (Carter, 1961; Lazaro, 1990; Harbor, 1994; Moscrip and Montgomery, 1997). Increasing concern about the problems caused by urban sprawl has encouraged development and implementation of smart growth approaches to land use management. Land managers and urban planners have long realized the importance of land allocation in urban planning, however, the development of a land acquisition strategy has generally not been included as part of the formal planning process. The reason for this neglect is largely the lack of good analytical tools for modeling land allocation, although this need has been expressed by land managers, decision makers, urban planners, and others. In particular, little or no research has been conducted in the field of applying spatial optimization techniques to land use planning from the perspective of minimizing surface runoff and associated NPS pollutants. To investigate the magnitude of the potential benefits of land use planning for water resources protection, possible runoff impacts of historical and projected urbanization were estimated for two watersheds in Indiana and Michigan using a long-term hydrological impact analysis model.

### **Research Objectives:**

The proposed work builds on significant past and ongoing efforts to quantify the impacts of land use change or urbanization on long-term runoff and NPS pollution (see <http://www.ecn.purdue.edu/runoff/>). Researchers at Purdue have developed a simple, user-oriented hydrologic and non-point source pollution impact assessment model (Harbor, 1994; Bhaduri et al, 1997, 2000; Pandey et al, 2000, 2001; Grove et al., 2001). Making use only of data readily available to the public, web-based and downloadable GIS versions of the model can be used by planners, consultants, farmers, and decision makers to assess the relative impacts of past, present, and alternate future land management decisions. Model results make use of location-sensitive data, such climate, land use, and soils, and thus the user can generate results for a specific watershed or subwatershed. In addition, the model allows users to modify parameters such as nonpoint source pollutant loading rates, based perhaps on local data or management approaches, and thus the model is flexible enough to allow for very local and site specific comparisons of different management alternatives. The model is simple to use, and is freely available at [www.ecn.purdue.edu/runoff/](http://www.ecn.purdue.edu/runoff/).

The work presented here illustrates both an approach to assessing the magnitude of the impact of smart growth, and the significant potential scale of smart growth in moderating runoff changes that result from urbanization. We have investigated the potential benefits of optimizing land use placement patterns to minimize impacts on water resources. The specific objectives of this study were: (1) to quantify possible runoff reductions of historical and projected urbanization by optimizing the placement of land use change within representative watersheds, and (2) to evaluate actual and projected development plans in terms of the potential minimum and maximum runoff impact of the development.

## Methods:

### *Study Areas*

This study was conducted in two watersheds: Little Eagle Creek (LEC) and Little Muskegon River (LMR), which represented actual and projected urban development, respectively. The LEC watershed, 70.4 km<sup>2</sup> in area, is located in the northwest side of Indianapolis, Indiana, and its suburbs (Figure 1). Because of its proximity to the city, this watershed has experienced rapid and extensive urbanization over the past three decades, which constitutes a potential threat to the water resources of the watershed. Land uses ranging from non-urban natural grass, forested areas, and agricultural areas to typical urban residential, and commercial categories exist in the LEC watershed. As of 1973, the land use distribution was 48.3% urban, 15.3% agriculture, 19.5% forest, and 15.5% grass, with the remainder (0.4%) in open water (Grove et al., 2001).

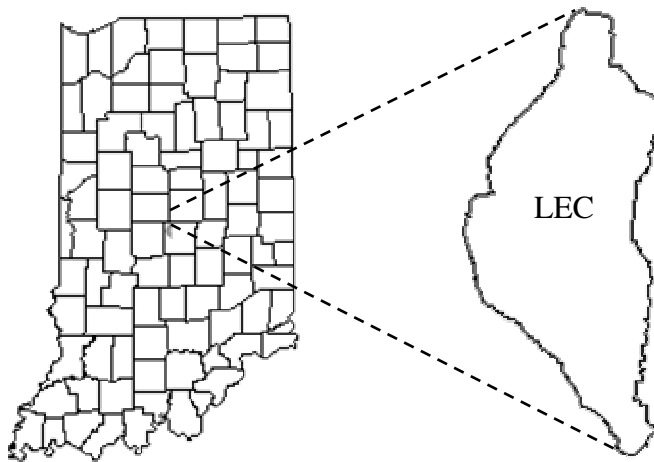


Figure 1. The Location of the Little Eagle Creek Watershed.

The LMR watershed is part of the Muskegon River watershed located on the east side of Lake Michigan in north-central Michigan. The Muskegon watershed consists of forty subwatersheds defined by USGS 14 digit hydrologic unit codes (HUCs). The three HUCs (38, 39, and 40) along the coast of Lake Michigan were grouped and named LMR by the authors in order to simplify the explanation for the rest of the paper (Figure 2). Surface water from HUC1 and HUC2 drains into HUC3. The LMR watershed covers an area of 332 km<sup>2</sup>. HUC3 accounts for half of the total LMR watershed area, the other half is shared by HUC1 (37%) and HUC2 (13%). The city of Muskegon is partially located in HUC3. In a parallel study (Tang et al., 2003), LMR was predicted as the most urbanized watershed with significant runoff impact among the forty subwatersheds of the Muskegon River watershed. As of 1978, the land use distribution of LMR was 24.1% urban, 13.3% agriculture, 42.4% forest, 8.8% grass, 10.8% water, with the remainder (0.6%) in bare soil.

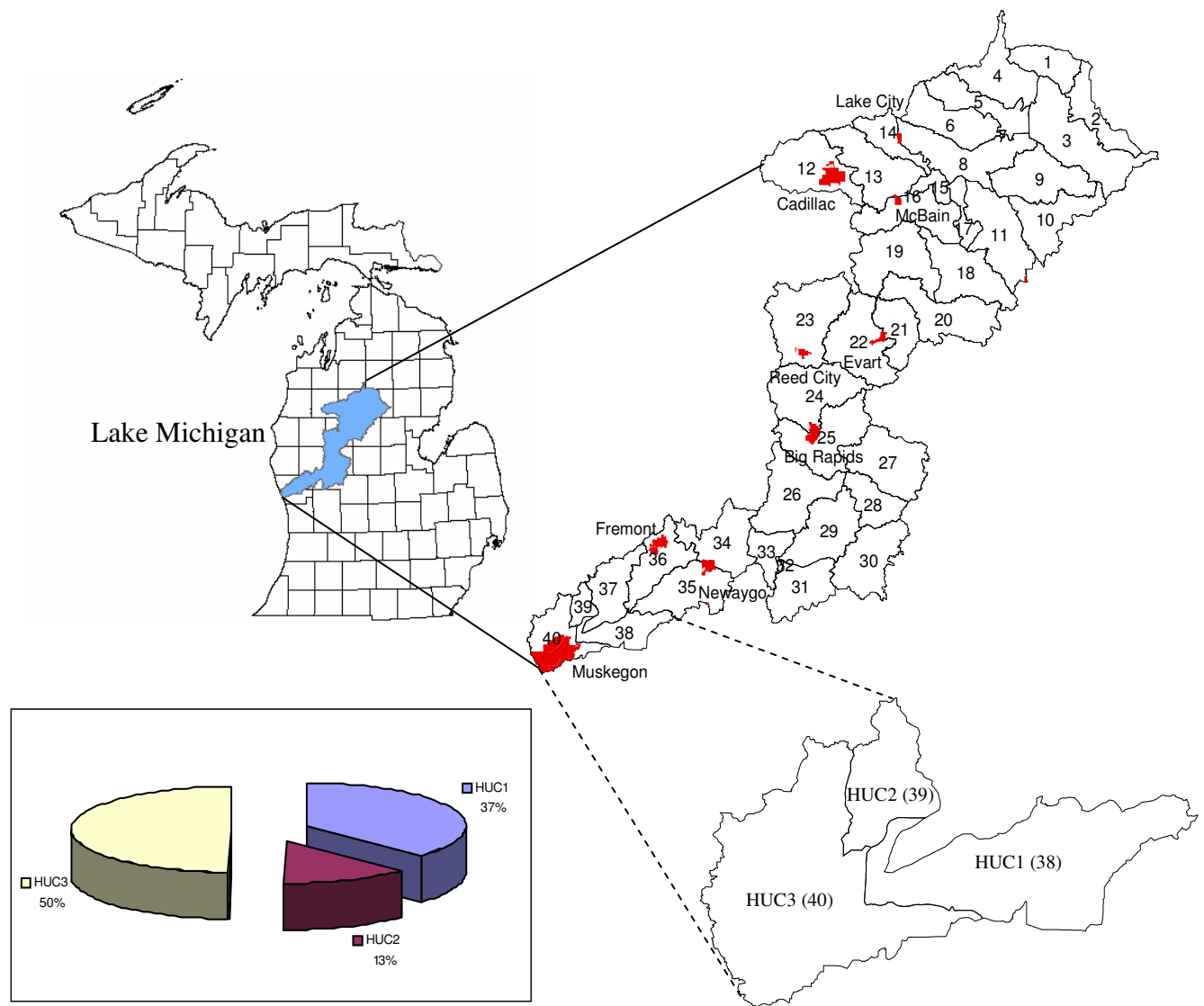


Figure 2. The Location of the Little Muskegon River Watershed and the Area Distribution of HUCs. The dark areas shown in the Muskegon River Watershed are cities.

### ***Enhancement of the Long-Term Hydrologic Impact Assessment (L-THIA) model***

The Long-Term Hydrologic Impact Assessment model, LTHIA (Harbor, 1994; Pandey et al., 2000), was enhanced and then employed for runoff optimization in this study. The L-THIA model is a straightforward assessment tool that provides estimates of changes in runoff, recharge, and NPS pollution resulting from past or proposed land-use changes (Harbor, 1994). It gives long-term average annual runoff and NPS pollutants for a land use configuration based on actual long-term climate data, soils, and land-use data for an area (Figure 3). The core of the model is based on the Curve Number (CN) method (NRCS, 1986), a widely applied technique for

estimating the change in discharge behavior as a watershed undergoes urbanization. Pollutant loading rates are used to quantify NPS pollutants (Pandey et al., 2000). By applying the method to actual and proposed urban developments, the long-term effects of past, present, and future land use can be assessed (e.g., Leitch and Harbor, 1999, Minner et al., 1998, Bhaduri et al., 2000). A detailed description of the model structure and approach can be found in Harbor (1994), Bhaduri et al. (2000), and Pandey et al. (2000). The L-THIA model is freely accessible in web-based and downloadable GIS versions (<http://www.ecn.purdue.edu/runoff/lthianew/>).

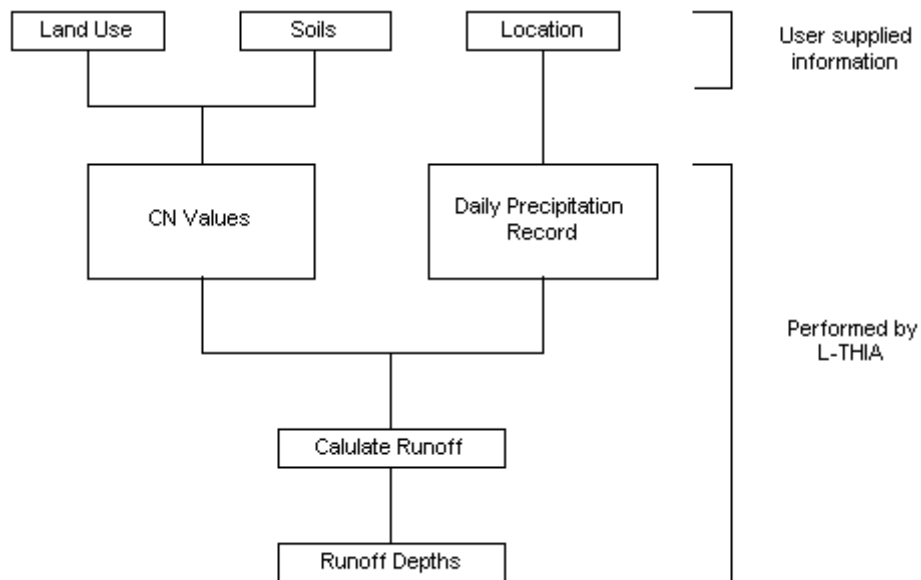


Figure 3. Basic Data Requirements and Components for Analysis in the L-THIA Model (Pandey et al., 2000).

Making use of data that are readily available to the public, the L-THIA model can be used to assess the relative impacts of past, present, and alternate future land management decisions. However, the L-THIA model is not capable of evaluating a development plan with respect to its potential minimum and maximum levels of impact. This research extended the capabilities of the existing and widely used web version of the L-THIA model by developing a runoff optimization component called ROMIN (RunOff MINimization). ROMIN applies a simple model with only an area constraint and a straightforward solution algorithm to provide general estimates of minimum runoff impacts due to land use change.

### **Principal findings and significance:**

Both historical and projected urban development in the LEC and LMR watersheds increase runoff significantly. This impact can be minimized by careful land use planning. Runoff increase can be reduced as much as about 4.9% from 1973 to 1997 in the LEC watershed which is almost totally urbanized, with 95% urban cover in 1997. The reduction of runoff increases from projected development will be as much as 12.3% and 20.5% for the non-sprawl and sprawl scenarios, respectively, in the entire LMR watershed from 1978 to 2040. The magnitude that runoff can be minimized depends on site specific land use types, soil properties, and the urbanization level of a watershed. The influence of urbanization can be generally expressed in two ways. On the one hand, with the increase of urban proportion within a watershed, its impact will be generally expected to increase and therefore the room to minimize this impact also increases potentially. On the other hand, when urban becomes the predominant land use in the area, the available non-urban areas become limited and the possibility and room to minimize the runoff impact will be very small. This was the case in the LEC watershed. Urban uses made up about 50% of the total watershed area in 1973. By 1997, the urban proportion increased to 95% of the total area. The available non-urban area for planning in 1997 was thus only 5%. Although the runoff increase due to development is as large as 69%, it can only be reduced by 4.9%. Therefore, land use planning at an early stage of development is much more effective. Few future planning options exist if urbanization trends continue.

The optimization component of the enhanced L-THIA, ROMIN, satisfied the need for an inexpensive computation approach required by the web executable L-THIA model. It also established the basis for the enhanced L-THIA to be an easy-to-use and easy-to-access land use planning tool. However, it has limitations compared to more sophisticated and computationally expensive spatial optimization models (Wright et al., 1983; Minor and Jacob, 1994; Williams and ReVelle, 1996; Brookes, 1997; Lin and Kao, 1999). In particular, the resultant optimal placement of proposed land uses on available land use and soil group patterns may not be contiguous because the model does not have a constraint for contiguousness to force spatially connected development. Such solutions may not be realistic for development in some cases, but the optimization approach would allow proposed solutions in such instances to be evaluated with respect to the optimal and worst case development scenarios. To overcome this limitation, on-going research efforts employ a multiobjective spatial optimization model with constraints including contiguousness, compactness, and shape, to allocate proposed land uses. However, this spatial optimization model is a computationally expensive solution algorithm, which means that the user must accept relatively lengthy computation times before a result is produced.

The enhanced L-THIA model assumes proposed urban development occurs only in non-urban land use, as it is a major development style in urban sprawl. This assumption can be removed if a more comprehensive analysis of land use change, including urban to urban change, is required.

The estimated runoff impact for the LEC and LMR watersheds in this study are potential minimums and maximums that do not account for regulatory or other social or economic restrictions on the placement of development which would modify the optimization results. For example, a farm land protection regulation may restrict development on agricultural land, which may increase the estimated minimum runoff increase. A wetland protection regulation may restrict development in wetland areas, which may reduce the estimated maximum runoff increase. Since the enhanced L-THIA model provides the option that allows users to specify

restricted land uses, the effects of regulation that consider land use protection can certainly be considered when necessary.

The results of this study have significant implications for urban planning. They suggest that even relatively simple internet-accessible tools can provide significant guidance regarding the potential reductions in runoff that can be achieved if urbanization locations are selected to minimize runoff changes. The runoff model L-THIA enhanced by the optimization technique provides a decision support capability that can be used by land use planners and other decision makers to identify land use plans that minimize runoff for a desired set of land uses. As a result, planners and developers could modify the location of proposed land use changes to reduce environmental impacts. In other instances planners and developers may wish to compare the impact of proposed development to the optimal situation. Regulations could presumably be developed based on the results of this work that require land use plans to minimize impacts on runoff, or incorporate best management practices that would allow the area they wish to develop to achieve runoff levels that are comparable to the optimal location for the planned development.

### **Information transfer activities:**

1. Submitted to JAWRA (Journal of American Water Resources Association):  
*Minimizing the Impact of Urbanization of Long-Term Runoff*  
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2. The L-THIA model is freely accessible in web-based and downloadable GIS versions (<http://www.ecn.purdue.edu/runoff/lthianew/>).

### **Students supported:**

Ms. Zhenxu Tang, graduate student, Department of Agricultural and Biological Engineering.

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